Claims

1. A switching amplifier adapted to drive at least first and second reactive loads with first and second switching signals, respectively, each of said first and second switching signals having respective switching band components and at least one respective baseband component, the baseband components of the first and second switching signals being such that, and said loads being interconnected in such a way that, for at least one signal variable for each load, the sum of the values of that particular signal variable is substantially constant.

2. The invention of claim 1 wherein said at least one signal variable is one of a) the current through said each load, b) the voltage across said each load, c) the charge stored in said each load, d) the energy stored in said each load, and e) a function of one or more of a) through d).

3. The invention of claim 2 wherein there are N of said loads and wherein for each of a number of signal variables for each load, the sum of the values of each particular signal variable is substantially constant.

4. The invention of claim 3 wherein said number of signal variables is greater than 1 and less than N.

5. The invention of claim 2 wherein respective first terminals of each of said loads are connected to a common node through which said current at baseband frequencies flows.

6. The invention of claim 5 wherein each of said loads has a second terminal and wherein said switching amplifier further comprises means for applying at

least the baseband components of said first switching signal between the second terminal of said first load and said common node and for applying at least the baseband components of said second switching signal between the second terminal of said second load and said common node.

7. The invention of claim 2 further comprising a mechanical load connected to at least one of said reactive loads.

8. The invention of claim 7 wherein said mechanical load includes means for generating acoustic sonar signals.

9. A switching amplifier adapted to drive at least first and second reactive loads with first and second switching signals, respectively, each of said first and second switching signals having respective switching band components and at least one respective baseband component, the baseband components of the first and second switching signals being such that, and said loads being interconnected in such a way that, substantially all of the current at baseband frequencies flowing out of one or more of said loads at a given time flows into one or more of the others of said loads.

10. The invention of claim 9 wherein respective first terminals of each of said loads are connected to a common node through which said current at baseband frequencies flows.

11. The invention of claim 10 wherein each of said loads has a second terminal and wherein said switching amplifier further comprises means for applying at least the baseband components of said first switching signal between the second terminal of said first load and said common node and for applying at least the baseband components of said second switching signal between the second terminal of said second load and said common node.

12. The invention of claim 11 wherein said switching amplifier is further adapted to drive a third reactive load with a third switching signal, said third load having a second terminal, and wherein said switching amplifier further comprises means for applying at least the baseband components of said third switching signal between the second terminal of said third load and said common node.

13. The invention of claim 9 wherein said loads have substantially equal impedance and wherein said baseband components are the inverse of one another.

14. The invention of claim 9 wherein said switching amplifier includes at least one power supply terminal and wherein said current flowing out of one or more of said loads flows away from said power supply terminal and said current flowing into one or more of the others of said loads flows toward said power supply terminal.

15. The invention of claim 14 wherein the phases and amplitudes of said baseband components are such that said currents add to zero at substantially all times.

16. The invention of claim 14 wherein respective first terminals of each of said loads are connected to a common node through which said current at baseband frequencies flows.

17. The invention of claim 9 wherein there are two of said loads, wherein said two loads have substantially equal impedances and wherein the baseband components of said first and second switching signals are of substantially equal magnitude and are substantially the inverse of one another.

18. The invention of claim 9 wherein said switching amplifier is further adapted to drive a third reactive load with a third switching signal, wherein said first, second and third loads have substantially equal impedances and wherein the baseband

components of said first, second and third switching signals are such that they add to zero at substantially all times.

19. The invention of claim 9 further comprising a mechanical load connected to at least one of said reactive loads.

20. The invention of claim 19 wherein said mechanical load includes means for generating acoustic sonar signals.

21. The invention of claim 9 wherein said switching amplifier includes at least first and second signal paths containing said first and second loads, respectively.

22. The invention of claim 21 wherein alternating polarity currents flow in said first and second signal paths in response to said first and second switching signals, respectively.

23. The invention of claim 22 wherein said first and second switching signals are generated in response to first and second pulse-width-modulated signals, respectively.

24. The invention of claim 21 wherein said switching amplifier further includes means for applying said first and second switching signals to said first and second signal paths, respectively, in such a way that at least one switching band component of said first switching signal and at least one switching band component of said second switching signal cancel each other and therefore are substantially isolated from said loads.

25. The invention of claim 24 wherein alternating polarity currents flow in said first signal path in response to said first switching signal and alternating polarity currents flow in said second signal path in response to said second switching signal.

26. The invention of claim 24 wherein

said at least one switching band component of said first switching signal and said at least one switching band component of said second switching signal are of substantially the same amplitude and phase, and

said means for applying comprises a common-mode inductor in said first and second signal paths.

27. The invention of claim 21 wherein said switching amplifier is further adapted to drive a third reactive load with a third switching signal, wherein said switching amplifier includes at least a third signal path containing said third load, and wherein said switching amplifier further includes means for applying said first, second and third switching signals to said first, second and third signal paths, respectively, in such a way that at least one switching band component of each of said first, second and third switching signals cancel each other and therefore are substantially isolated from said loads.

28. The invention of claim 27 wherein alternating polarity currents flow in said first signal path in response to said first switching signal, alternating polarity currents flow in said second signal path in response to said second switching signal, and alternating polarity currents flow in said third signal path in response to said third switching signal.

29. The invention of claim 27 wherein

said at least one switching band component of said first, second and third switching signals are of substantially the same amplitude and phase, and

said means for applying comprises a common-mode inductor in said first, second and third signal paths.

30. The invention of claim 21 wherein

each of said loads includes a first terminal and a second terminal,

the first terminals of each of said loads are connected to a common node through which said current at baseband frequencies flows,

each said path includes filtering circuitry connected to the second terminal of the respective load, and

each of said first and second switching signals comprises an alternating polarity signal impressed across said first and second signal paths, respectively.

31. The invention of claim 21 wherein

each of said loads includes a first terminal and a second terminal,

the first terminals of each of said loads are connected to a common node through which said current at baseband frequencies flows, said common node being connected to a fixed potential,

each said path includes filtering circuitry connected to the second terminal of the respective load, and

said first and second switching signals comprise respective signals at first and second potentials applied to the filtering circuitry of said first and second signal paths, respectively.

32. The invention of claim 31 wherein

said second potential is substantially equal to said fixed potential, and

said filtering circuitry includes at least one energy storage element that stores energy when each said switching signal is at said first potential and that supplies energy to said loads when each said second node is connected to said second potential.

33. The invention of claim 32 wherein

said energy storage element is a common-mode inductor having first and second ports in said first and second paths, respectively, and

said first and second switching signals have respective switching band components that are of substantially equal magnitude and phase that are canceled by said common-mode inductor.

34. Apparatus comprising

two or more circuit paths each including a respective reactive load, each of said loads having a first terminal connected to the first terminal of each other load,

means for generating for each of said circuit paths an associated pulse-width-modulated signal, each pulse-width-modulated signal alternating between a respective first level and a respective second level at a particular switching frequency, the pulse widths of the pulses of each pulse-width-modulated being determined by a respective baseband signal,

means responsive to each of said pulse-width-modulated signals for impressing an associated switching signal across the associated circuit path, said switching signal comprising first and second voltages impressed across the associated circuit path when the associated pulse-width-modulated signal is at its first and second levels, respectively,

the baseband signals being such that substantially all of the current at baseband frequencies flowing out of one or more of said loads at a given time flows into one or more of the others of said loads.

35. The invention of claim 34 wherein there are N of said circuit paths and wherein the phase of each of the baseband signals differs from the phase of one other of said baseband signals by 360/N degrees.

36. The invention of claim 34 wherein said circuit paths include circuitry in common that prevents current at at least said switching frequency from flowing through said loads.

37. The invention of claim 34 wherein said circuit paths include in common circuitry that isolates signals at at least said switching frequency from said loads.

38. The invention of claim 34 wherein said circuit paths include in common circuitry that cancels signals at at least said switching frequency.

39. The invention of claim 34 wherein said switching signals are in phase with one another at said switching frequency and wherein said circuit paths include respective ports of a common-mode inductor that cancels signals at at least said switching frequency, thereby preventing most of the energy in said switching signals at said switching frequency from being applied to said loads.

40. The invention of claim 39 wherein $N \geq 3$.

41. The invention of claim 34 further comprising a mechanical load connected to at least one of said reactive loads.

42. The invention of claim 41 wherein said mechanical load includes means for generating acoustic sonar signals.

43. A switching amplifier adapted to drive at least one reactive load with two or more switching signals having the same switching frequency, each of said switching signals having respective switching band components and at least one respective baseband component, said switching amplifier including circuitry that processes said switching signals in such a way as to subtractively combine their respective frequency components at at least one frequency and thereby isolate signals at said at least one frequency from said at least one load.

44. The invention of claim 43 further comprising a mechanical load connected to at least one of said reactive loads.

45. The invention of claim 44 wherein said mechanical load includes means for generating acoustic sonar signals.

46. The invention of claim 43 wherein said circuitry comprises a common-mode inductor to which each of said switching signals is applied.

47. The invention of claim 46 wherein there are at least three of said switching signals.

48. The invention of claim 47 wherein said switching amplifier is adapted to drive at least three reactive loads with said at least three switching signals.

49. The invention of claim 43 further comprising load filtering circuitry that is effective to isolate from the load switching band components at other than said at least one frequency.

50. The invention of claim 49 wherein said at least one frequency is the fundamental frequency of said switching signals and wherein said load filtering circuitry provides substantial filtering only at higher-order frequencies of said switching signals.

51. The invention of claim 50 wherein said circuitry that processes said switching signals comprises a common-mode inductor to which each of said switching signals is applied.

52. Apparatus comprising

means for generating at least first and second switching signals having the same switching frequency and having respective fundamental frequency components that have a particular phase relationship with one another and said first and second switching signals having respective baseband components at at least one baseband frequency that do not have said particular phase relationship with one another,

at least first and second reactive loads,

a rejection filter that cancels signals applied to respective ports thereof that have said predetermined phase relationship, and

means for applying said at least first and second switching signals to respective circuit paths that include said at least first and second loads, respectively, and that include respective ports of said rejection filter, whereby signals at said fundamental switching frequency are isolated from said loads while said baseband components at at least said one baseband frequency are applied to said loads.

53. The invention of claim 52 wherein said fundamental frequency components are in phase with one another, said baseband components are the inverse of one another, and said rejection filter is a common-mode inductor.

54. The invention of claim 52 wherein

said at least first and second switching signals comprises at least first, second and third switching signals,

said apparatus further comprises a third reactive load, and

said apparatus further comprises means for applying said third switching signal to a respective circuit path that includes said third load and that includes a respective port of said rejection filter.

55. The invention of claim 54 wherein said rejection filter is a common-mode inductor.

56. The invention of claim 52 wherein said rejection filter is a common-mode filter, wherein said switching signals are phased in such a way that, and are applied to said common-mode filter in such a way that, said fundamental frequency components comprise a common-mode input signal for said common-mode filter and said baseband components are differential mode signals for said common-mode filter.

57. The invention of claim 56 further comprising a mechanical load connected to at least one of said reactive loads.

58. The invention of claim 57 wherein said mechanical load includes means for generating acoustic sonar signals.

59. Apparatus comprising

at least first and second reactive loads,

means for generating at least first and second switching signals having respective common-mode components at at least one switching frequency and having respective non-common-mode components at at least one baseband frequency, and

circuitry for applying said at least first and second switching signals through a common-mode rejection filter to said at least first and second reactive loads, respectively, so that said loads are isolated from said common-mode components at at least said one switching frequency, said circuitry being such that alternating polarity signals are applied to said loads.

60. The invention of claim 59 wherein said circuitry further comprises load filtering circuitry adapted to isolate switching band components of said switching signals from said loads, said load filtering circuitry having a passband that includes said fundamental switching frequency.

61. The invention of claim 60 further comprising a mechanical load connected to at least one of said reactive loads.

62. The invention of claim 61 wherein said mechanical load includes means for generating acoustic sonar signals.

63. A switching amplifier operating at a particular switching frequency, the switching amplifier comprising

at least first and second circuit paths,

each of said paths comprising switching circuitry, a load filter, a respective port of a common-mode inductor and a reactive load, all connected in series, each reactive load having a terminal that is connected to a node in common with each other reactive load, each load filter having a passband that includes said particular switching frequency and having a stop band at frequencies higher than said particular switching frequency,

said switching circuitry being operative in response to a first pulse-width-modulated signal to cause first and second voltages of a first switching signal to be alternately impressed between the load filter of said first circuit path and said common node and being further operative in response to a second pulse-width-modulated signal to cause first and second voltages of a second switching signal to be alternately impressed between the load filter of said second circuit path and said common node,

said first and second switching signals having respective fundamental switching components that are of substantially equal magnitude and phase so that they are canceled by said common-mode inductor, said first and second switching signals each further having at least one respective baseband component, the baseband components of said first and second switching signals being such that substantially all of the current at baseband frequencies flowing out of one or more of said loads at a given time flows into one or more of the others of said loads.

64. The invention of claim 63 wherein the phases and amplitudes of said baseband components are such that said currents add to zero at substantially all times.

65. The invention of claim 63 wherein said loads have substantially equal impedance and wherein said baseband components are the inverse of one another.

66. The invention of claim 63 wherein said switching amplifier includes at least one power supply terminal and wherein said current flowing out of one or more of said loads flows away from said power supply terminal and said current flowing into one or more of the others of said loads flows toward said power supply terminal.

67. The invention of claim 63 wherein there are two of said reactive loads having substantially equal impedances and wherein the baseband components of said first and second switching signals are of substantially equal magnitude and are substantially the inverse of one another.

68. The invention of claim 67 further comprising a mechanical load connected to at least one of said reactive loads.

69. The invention of claim 68 wherein said mechanical load includes means for generating acoustic sonar signals.

70. A switching amplifier using switching circuitry to alternatively connect two or more electrical loads to a power supply through filters that inhibit switching frequency currents from flowing in the loads.

71. The switching amplifier of claim 70 wherein at least one of said loads stores energy that is subsequently transferred to at least one of the other loads.

72. The switching amplifier of claim 70 wherein baseband currents flowing in said loads sum substantially to zero at all times.

73. The switching amplifier of claim 70 wherein said loads are capacitive loads.

74. The switching amplifier of claim 70 wherein there are at least three of said loads and wherein baseband currents flowing in said loads having respective different phases.

75. The switching amplifier of claim 70 wherein said filters include a common-mode inductor.

76. A method for use in a switching amplifier that uses at least two switching signals having switching band and baseband components to drive at least two loads, the method comprising

generating said switching signals in such a way that the common-mode energy of said switching signals is substantially all in the switching band and that the differential-mode energy of said switching signals is substantially all in the baseband, and

using common-mode rejection circuitry to isolate the switching band energy from said loads.

77. The switching amplifier of claim 76 wherein said common-mode rejection circuitry includes common-mode inductor to which each of said switching signals is applied via a respective port of said common-mode inductor.

78. A switching amplifier adapted to drive at least first and second balanced capacitive loads, each of said loads including a first terminal and a second terminal, said switching amplifier including

means for connecting the first terminals of each of said loads to a potential V_1, and

means for connecting the first terminal of each load through filtering circuitry alternately to a potential V_2 and a potential V_G,

wherein $V_2 > V_1 > V_G$.